New Data Sources to Revolutionize UAS Situational Awareness and Minimize Risk

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A2SYS LAB

What does a UAS "Need to Know"?

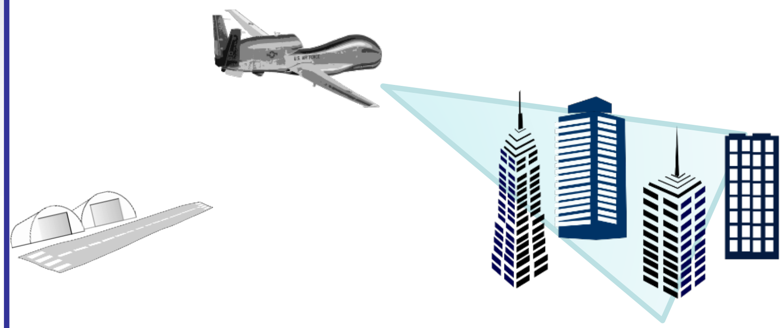
- **Mission: UAS transports payload**
  - Where does the UAS payload need to be carried?
    - Package Transport (fly from point A to point B)
    - Sensor Data Acquisition (coverage, surveillance target locations/properties, persistent airborne sensing)
  - How is sensor data collected, processed, and shared?
    - Store data for later use
    - Process data to adapt real-time behavior (flight plan/GNC, communication, data processing): Track target, observe feature of interest, identify/react to anomalies

- **Flight Planning + Guidance, Navigation, and Control (GNC):**
  - Current capabilities: Optimize baseline flight plan and GNC systems given vehicle dynamics, envelope constraints, energy dynamics and constraints
  - What in-flight anomalies might be encountered, and what needs to be known?
    - Environment: wind, precipitation, terrain/structures, other vehicles
    - Vehicle: faults/failures, conflicting commands
    - Mission: faults/failures, changes from operator/payload management system
  - *How can flight planner + GNC systems adapt to anomalies/opportunities?*

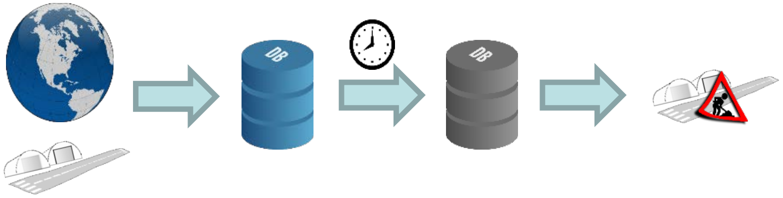
Data→Information for UAS Situational Awareness

Sensors and Databases Complement Each Other

Sensors: Real-time data
Available with or w/o link
Restricted to field of view



Databases: Large-area, diverse data
Comprehensive, high-accuracy data
Data may be outdated
Dynamic events/objects not captured



* Sensor data by default collected onboard single UAS, but could be shared among collaborating UAS, V2I2V (V=vehicle, I=infrastructure)

* Database information available via a priori storage + V2C2V (C = cloud)

Where is the “machine learning”?

- UAS Flight Plan Execution: Adaptive guidance and control
  - Guide vehicle toward target, away from obstacles
  - Adapt feedback control gains/structure to stabilize and track reference commands

- UAS Information & Flight Management: Update mission, flight plan
  - Offline: Prepare models and data for each aircraft, mission, flight
  - Online: Alter mission goals, payload data collection and processing, and/or flight plan in response to anomalies and opportunities

- *Autonomous Aerospace Systems (A2Sys) Lab: Primary focus on Information and Flight Management*

What do pilots know, how do they adapt?

Pilot Behaviors to PREVENT

Pilot Behaviors to Capture

Autonomy for Safety: Outline

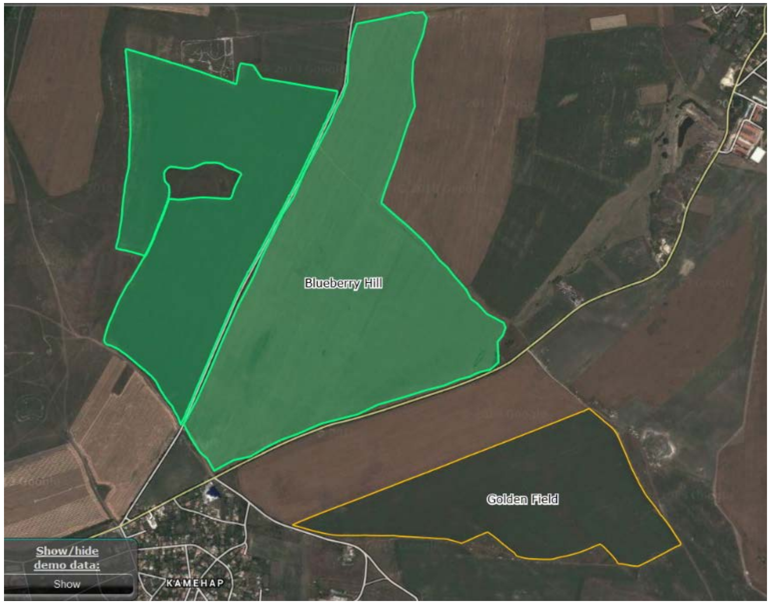
- **Topic 1: Electronic Geofencing**
  - **<u>Keep-in:</u>** Prevent small UAS (sUAS) from flying outside an authorized flight range
  - **<u>Keep-out:</u>** Ensure sUAS do not fly in sensitive and/or high-risk areas

- **Topic 2: Emergency Landing Planning**
  - Step 1: Landing Site Selection (LSS)
  - Step 2: Emergency Landing/Flight Planning to that site
  - Applicable to UAS and manned aircraft (time scale shorter for sUAS)

- *Both of these autonomy "widgets" require "flight safety and assessment" (FSAM) logic to ensure appropriate activation*

What is Electronic Geofencing?

- A virtual "fence" to keep entities in or out
- 3-D Geofence Specification:
  - Altitude ceiling [floor opt.]
  - (Latitude, longitude) convex polygon boundaries
- Information required: Real-time inertial navigation (onboard), geofence boundaries (property maps?), airspace rules, traffic, …



Background: DJI Geofence

- Available geofencing for $\geq$ 7 systems
- Keep-in:
  - Cylindrical flight area
  - Maximum altitude geofence (20m to 500m)
  - Maximum radius geofence (15m to 500m)
- Keep-out:
  - Incomplete, strictly advisory No Fly Zone list
  - Enforced independent of availability of an internet connection

- Stops aircraft before breaching the boundary

Ardupilot Geofence – Plane

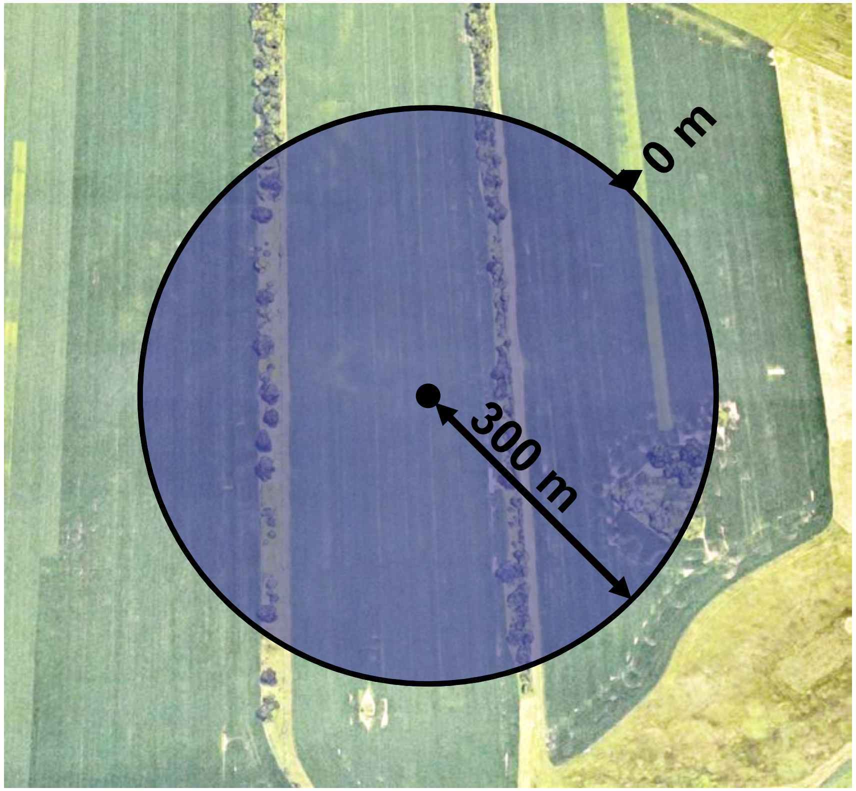
- Return to launch or waypoint ***after*** boundary breach
- Lateral geofence designated by waypoint list:
  - 4 to 18 edge points
  - First waypoint equals last waypoint
- Altitude geofence:
  - minimum and maximum altitude above ground level

Ardupilot Geofence – Copter

- Geofence definition:
  - Cylindrical flight area
  - Maximum lateral radius
  - Maximum altitude
- On breach:
  - System returns to launch

If pilot overrides RTL command → new geofence 20m out from current

Limit 100m from original geofence boundary → LAND

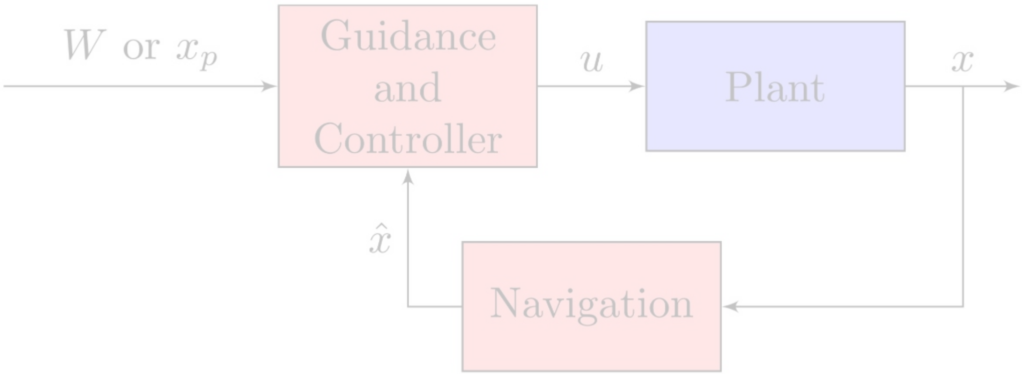


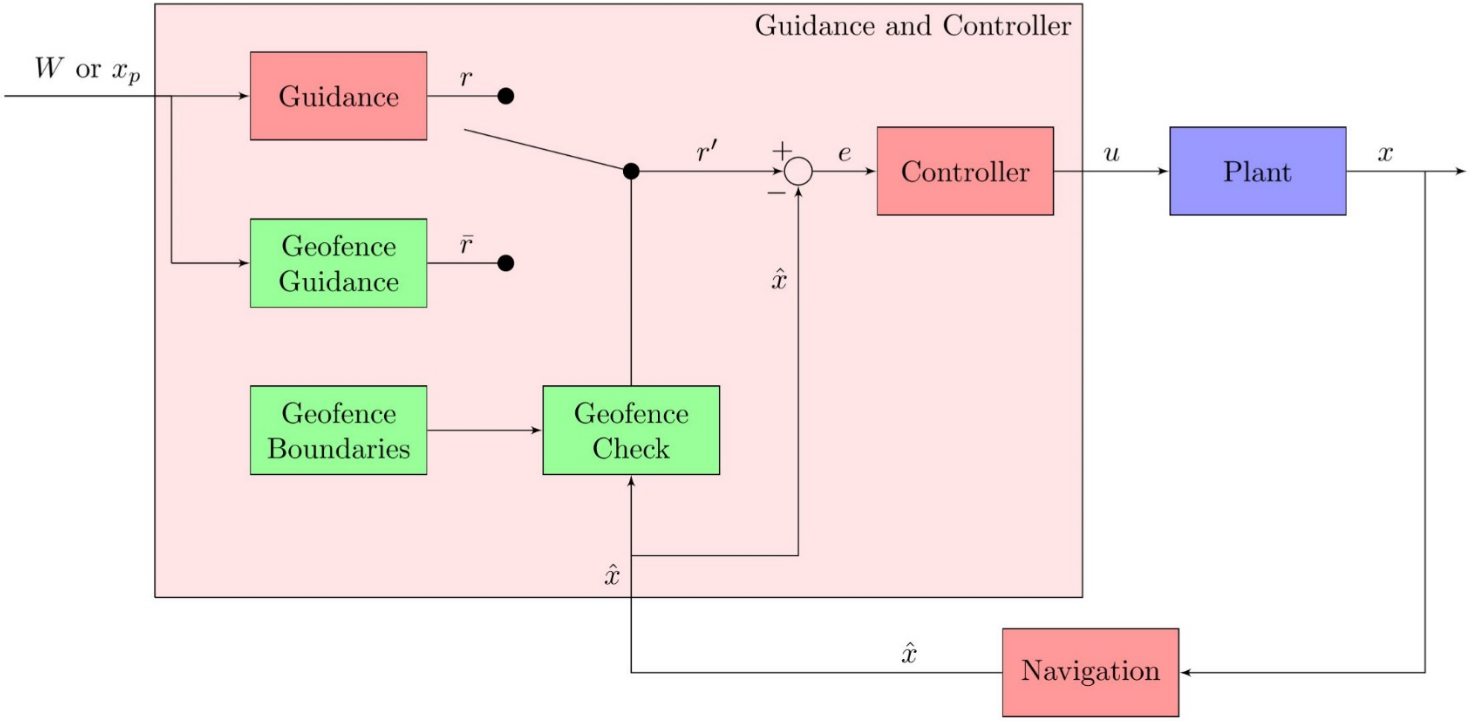
SUAS Geofence Operation

- Geofence system continuously monitors the SUAS 3-D location.
- If a keep-out fence boundary is encountered, the geofence overrides the nominal SUAS pilot/autopilot system to ensure the volume is avoided.
- If a keep-in fence boundary is encountered, the geofence overrides the nominal SUAS pilot/autopilot system to ensure the SUAS remains within the flight range volume.

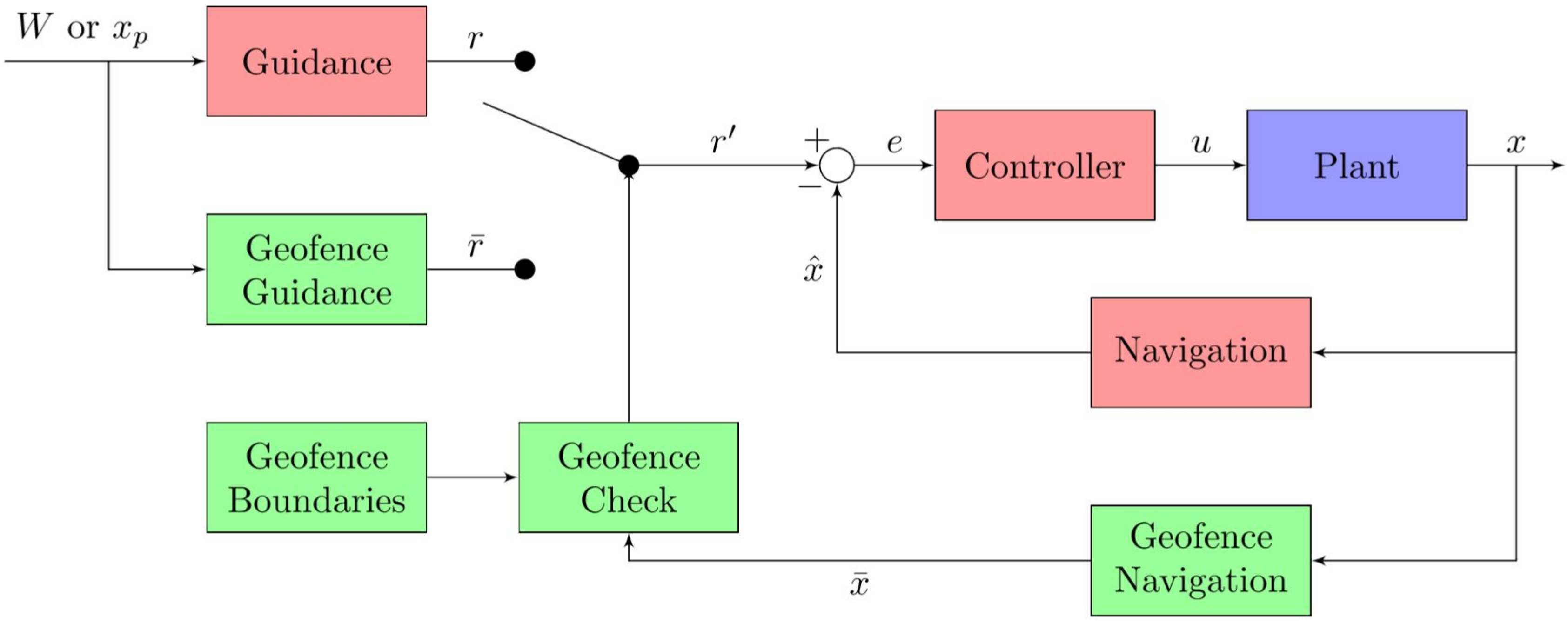
Current Geofence Systems

- Implemented by:
  - DJI
  - Ardupilot
- Outdoor systems
- Part of autopilot





Independent Geofence System



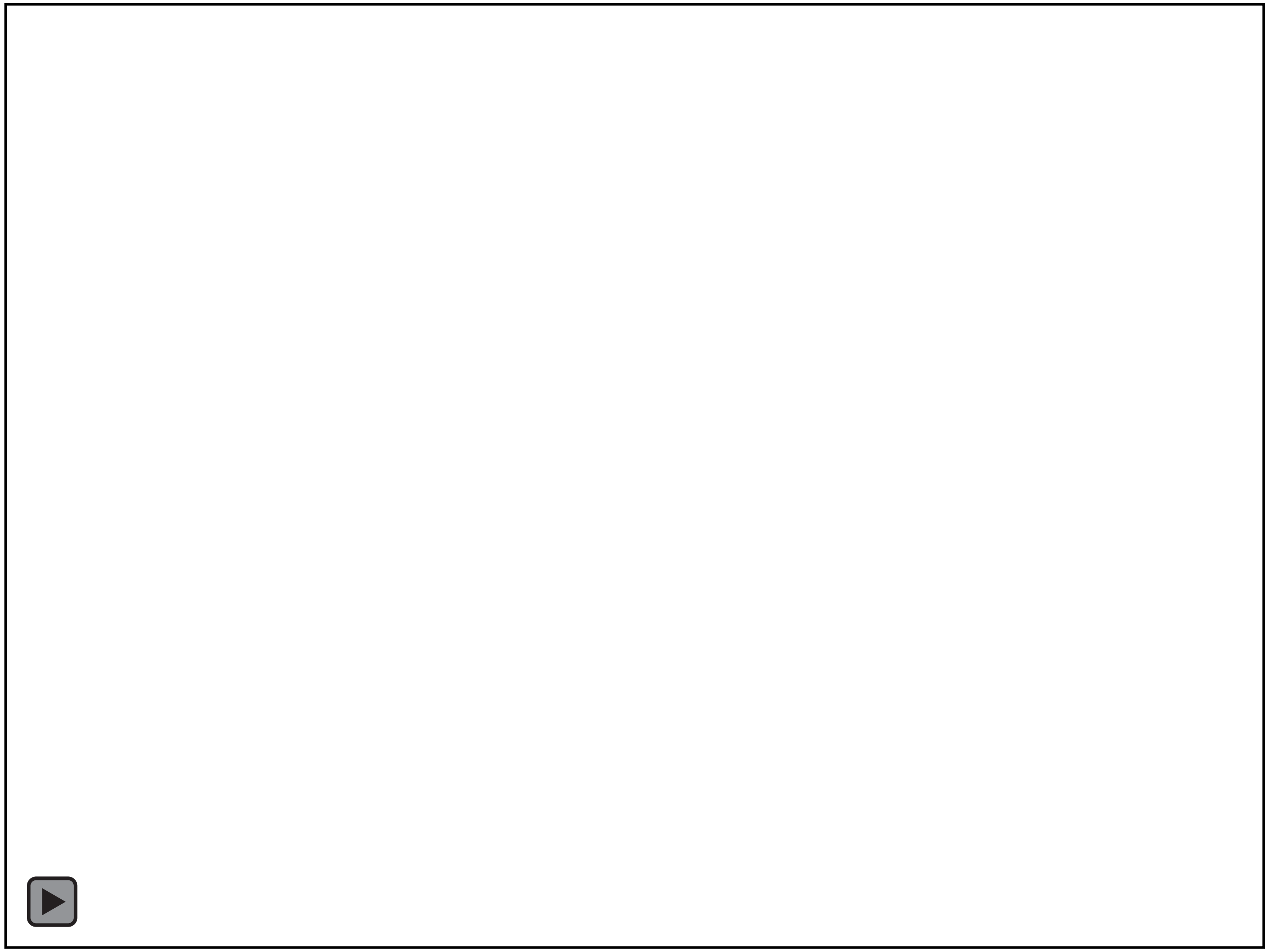
Separate software, processor, and sensors

Focus on Geofence Guidance

- Complements other research focusing on geofence control
- Currently define three possible operational modes for a geofence system:
  - Shared Control
    - Similar to DJI
  - Return to Launch (RTL)
    - Similar to Ardupilot Plane
  - Local Loiter (LL)
    - A variation on the RTL mode

Shared Control

Multicopter Position
Default Guidance
Geofence Boundary



Return to Launch (RTL)

- An imminent geofence breach causes the aircraft to:
  - Transition to hover
  - Fly directly to the launch location
  - Hover until the pilot reasserts control
- RTL mode impacts the default flight path enough to justify providing the pilot with the capability to turn the geofence system off and on to interrupt the command sequence.

Local Loiter

- Commands the vehicle to:
  - Transition to hover
  - Fly a specified distance inside the geofence
  - Hover until the pilot reasserts control
- Designed to appear as though the vehicle is bouncing off of the geofence boundary – less disruptive than RTL

SUAS Geofence: Issues to Resolve

- Operation (review):
  - Geofence system continuously monitors the SUAS 3-D location.
  - If a keep-out fence boundary is encountered, the geofence overrides the nominal SUAS pilot/autopilot system to ensure the volume is avoided.
  - If a keep-in fence boundary is encountered, the geofence overrides the nominal SUAS pilot/autopilot system to ensure the SUAS remains within the flight range volume.
- **No industry-standard behaviors have been defined, and no unit has been safety-certified to-date**
- **Open questions remain:**
  - **Control: How does feedback controller function accurately on all sUAS?**
  - **Guidance: Where does geofence direct the aircraft to avoid boundary breach?**
  - **Logic: How/when does fence activate and de-activate?**

Autonomy for Safety: Outline

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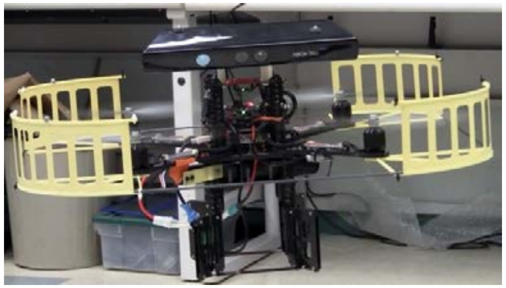
Onboard Sensors and sUAS

Significant amount of work has been dedicated to onboard sensors such as the usual Inertial Navigation Systems (INS) and :



Kinect

Ref: http://hybrid.eecs.berkeley.edu/~bouffard/kinect.html

Vision

Ref: http://www.csail.mit.edu/drone_flies_through_forest_at_30_mph

LIDAR

Ref: http://techcrunch.com/2015/01/06/with-skyspecs-guardians-the-drones-have-become-self-aware/

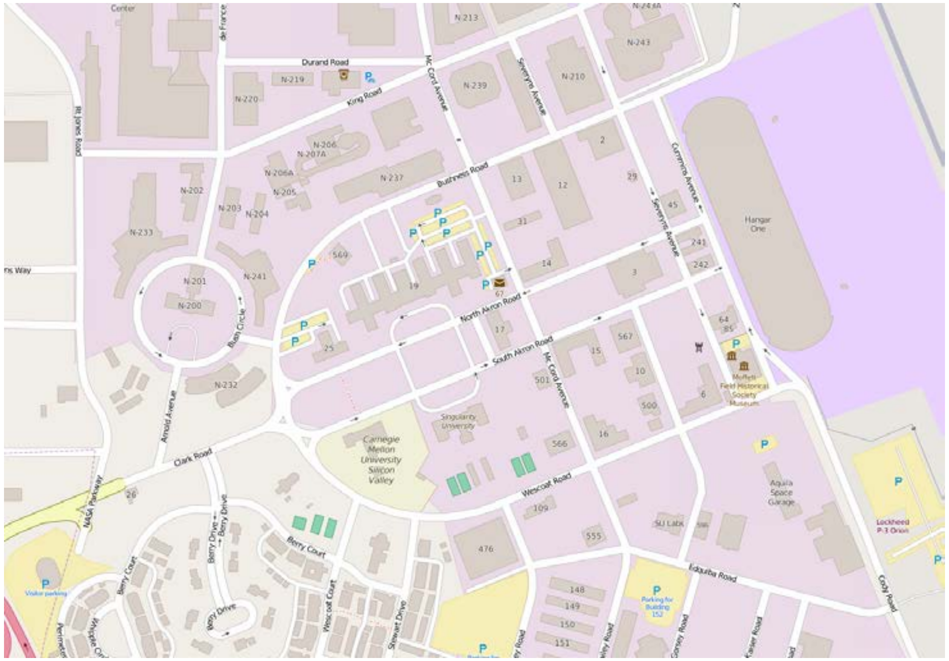
Ultrasound

Ref: http://www.panoptesuav.com/ebumper

Onboard Databases and sUAS

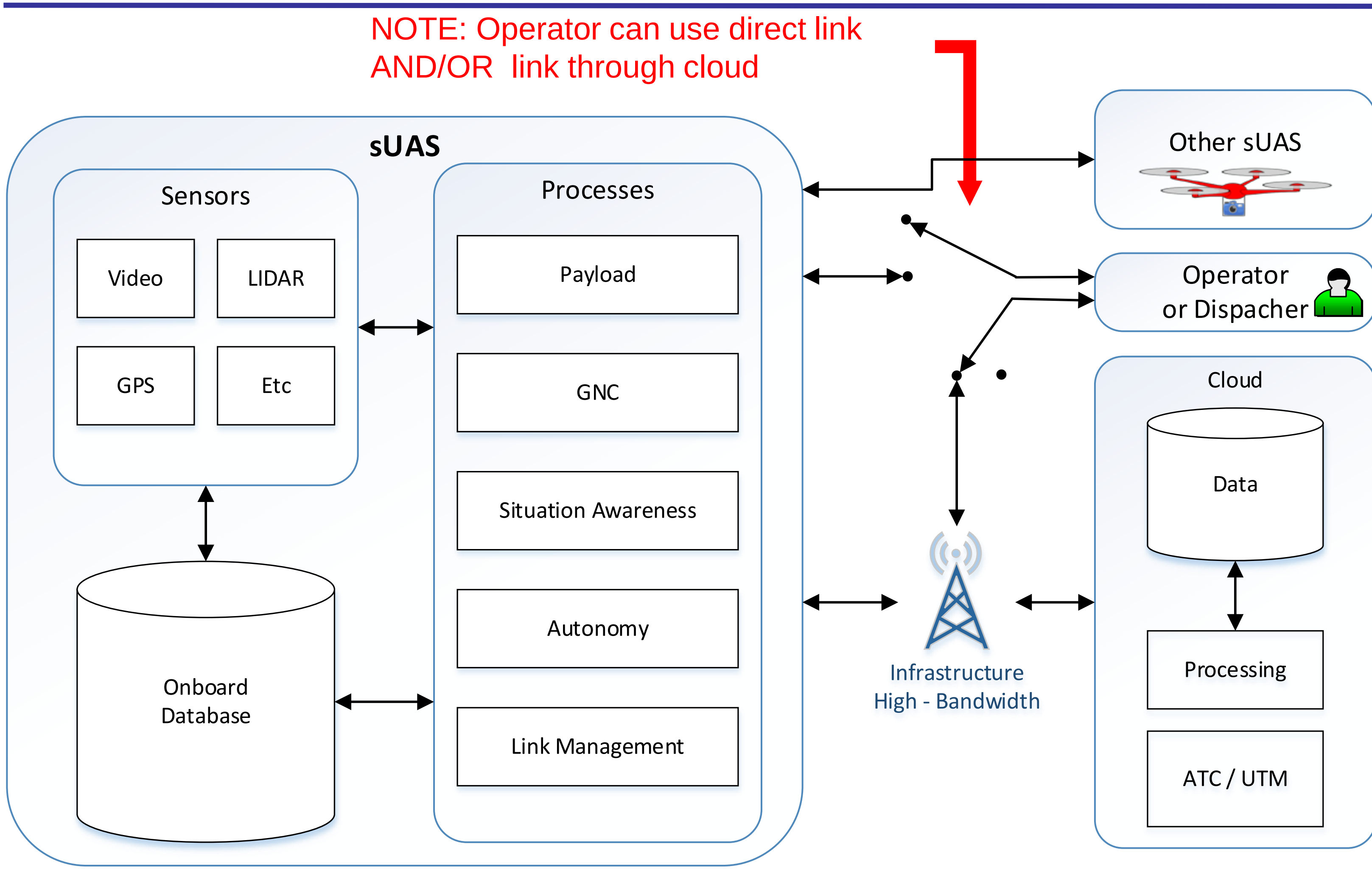
Smaller amount of work has been dedicated to databases:

- Huge amount of information available (even publicly)
- Onboard data storage possible without appreciable weight penalty
- Augment traditional aviation databases!!!



Ref: https://www.openstreetmap.org

sUAS Data-Enabled Operation with V2C2V



Database-Sensor Fusion

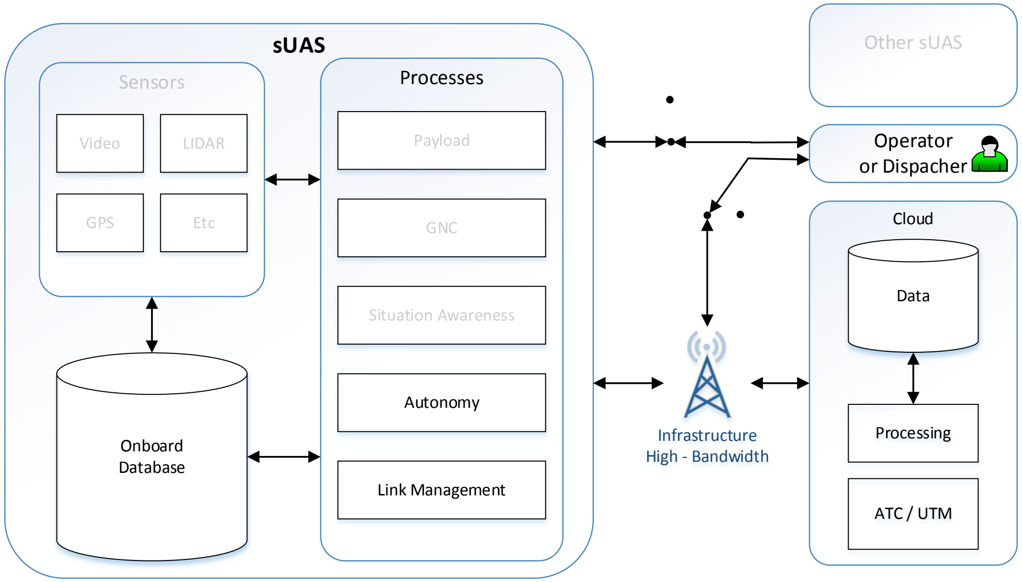
Combine the advantages of each source to maximize information available for decision-making:

Source	Advantages	Disadvantages
Onboard Sensors	Real-time data	Limited range / direction
Onboard Databases	Diverse, rich suite of pre-processed data	Can be out of date
Cloud	Real time Only interesting data can be used from huge databases	Needs connection and bandwidth

Database-Sensor Fusion – Pre-Flight

1) Flight planning is performed consulting different databases and negotiating with UAS Traffic Management (UTM) (cloud assumed available):

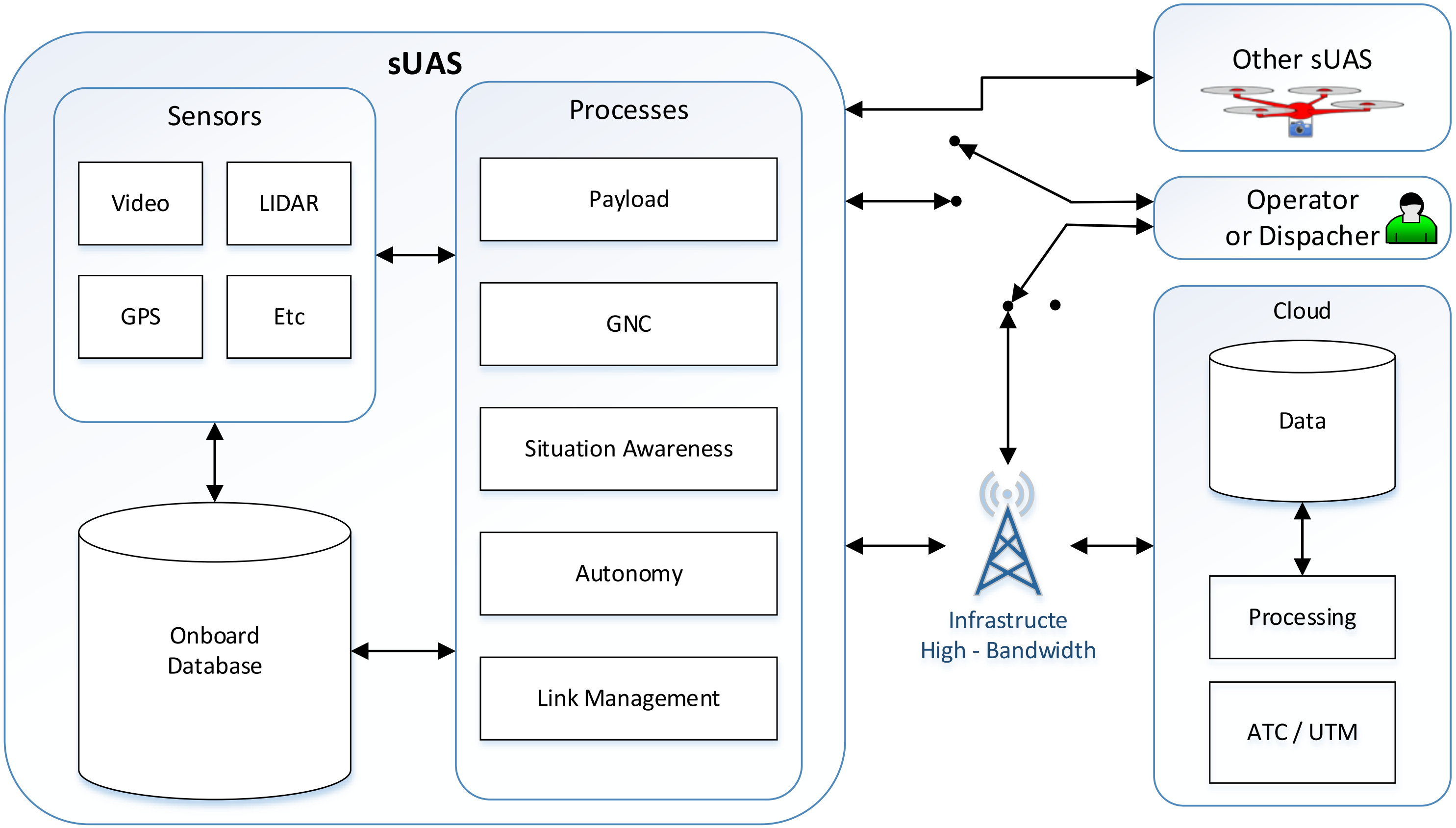
- Airspace and ground maps
- Destination and alternative fields
- Weather, obstacles
- Inflight sUAS-cloud connection availability estimative



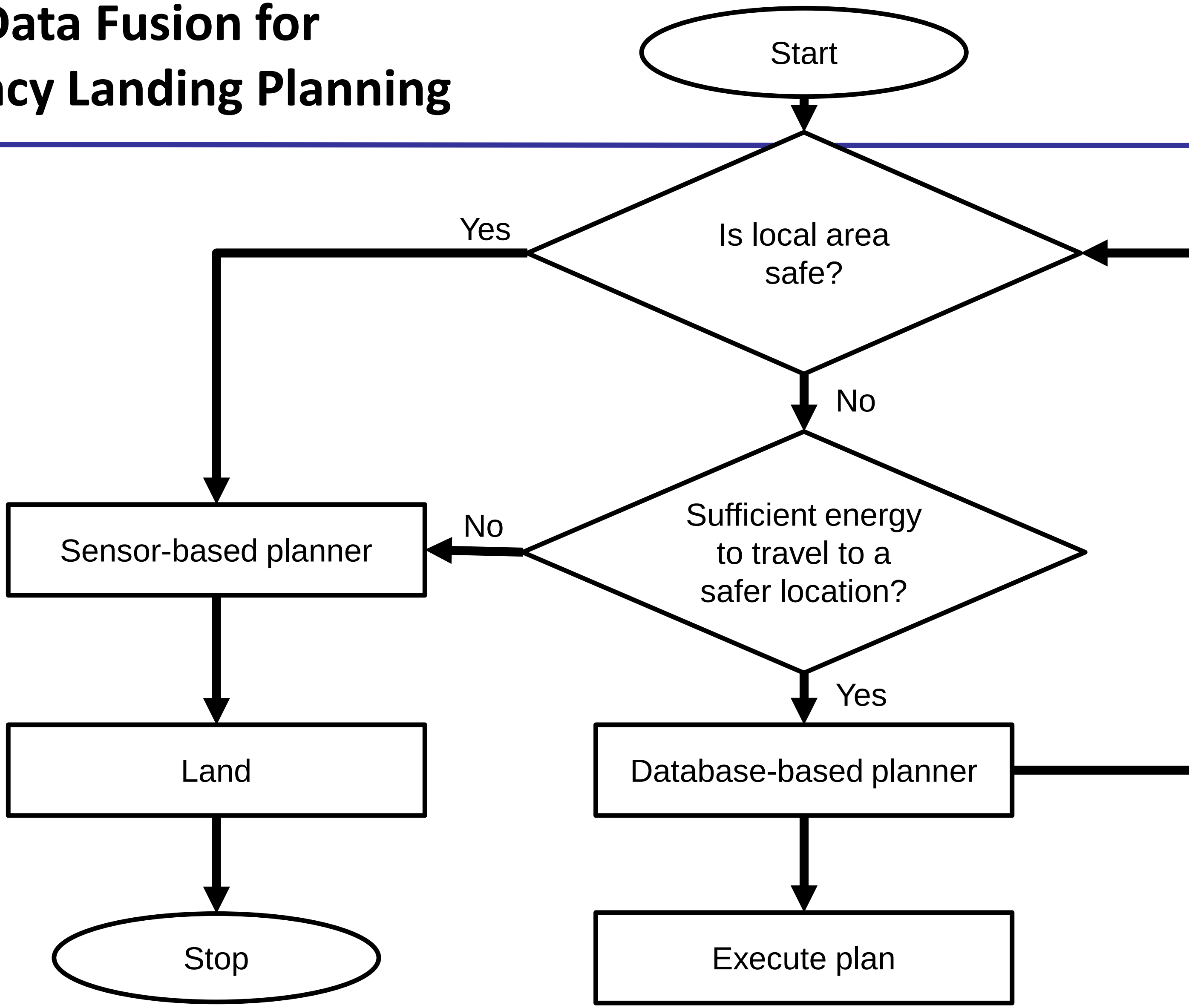
2) Relevant flight information is loaded on onboard databases

Database-Sensor Fusion – In Flight

Data fusion can serve as a surrogate to assure situational awareness



Sensor-Data Fusion for Emergency Landing Planning



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Ref: *Ten Harmsel, Alec J., Isaac J. Olson, and Ella M. Atkins. "Emergency Flight Planning for an Energy-Constrained Multicopter." Journal of Intelligent & Robotic Systems (2016): 1-21.*

Database-Sensor Fusion – In Flight

1) Data fusion examples for dealing with sensor failure:

- Map landmarks can be matched to sensed features as a backup to GPS.
- Unexpected winds and visibilities can be reported and correlated with nearby sUAS reports.

2) Data fusion use in emergency scenarios

- Onboard databases can provide fast candidate of emergency landing sites.
- Cloud connection can provide candidate emergency landing sites (with real time information) and guarantee free space from neighbor traffic.
- Onboard sensors can be used for final real-time landing site survey (e.g. to see if there are people on an open field in a park).

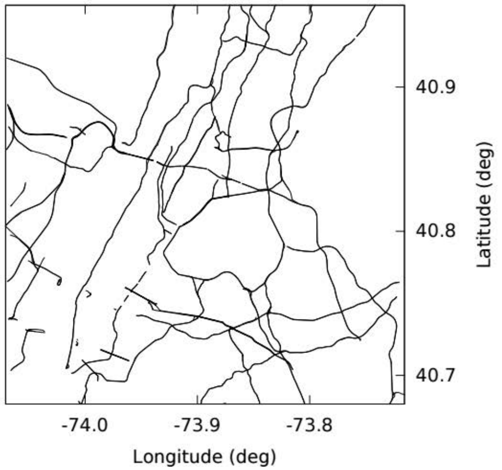
Road Database for Emergency Landing

Goal: to augment an adaptive flight planner to consider roads if no airport runway is feasible.

Preprocessing:
Publicly available database (openstreetmap.org)
⇩
Filter major roads
⇩
Detect straight lines
⇩
Eliminate segments with bridges
⇩
Candidate Landing Sites

Original Map

Major Road Extraction



Ref: Di Donato, Pedro F., and Ella M. Atkins. "An Off-Runway Emergency Landing Aid for a Small Aircraft Experiencing Loss of Thrust." In *AIAA Infotech@ Aerospace*, 2015.

Road Database for Emergency Landing

On-Board:

Determine Reachable Landing Sites (database)

⇩

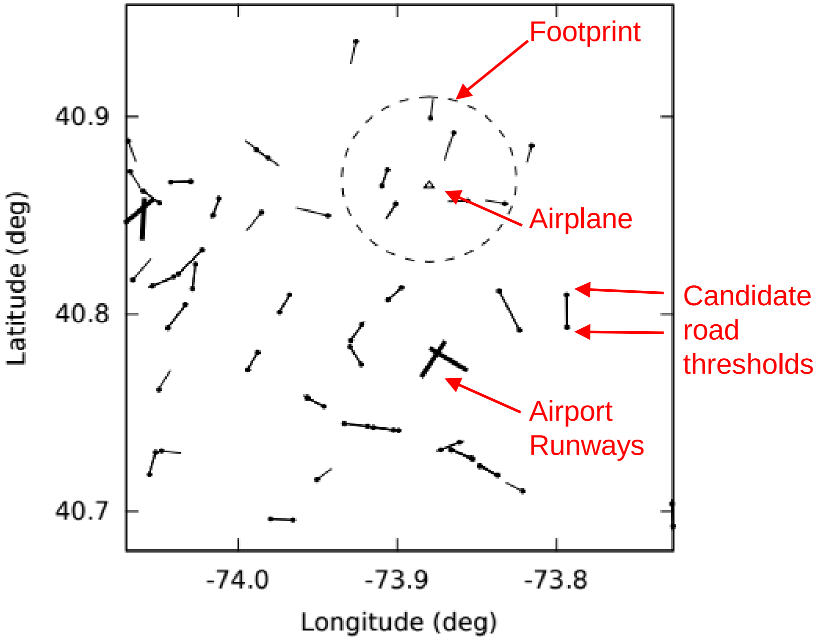
Check traffic (cloud)

⇩

Prioritize Landing Sites

⇩

Generate Path to Chosen One (autonomously or by pilot)



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Mobile-Phone Activity to Estimate Occupancy

Occupancy can change abruptly:

Ref: Ann Arbor News

Ref: ftw.usatoday.com

Is there a good way to obtain occupancy information in real-time?

This information can be very useful in an sUAS emergency scenario.

Mobile-Phone Activity to Estimate Occupancy

Goal: to verify if mobile phone activity data could be used as an occupancy information source for an UAS

Call Detail Report (CDR):

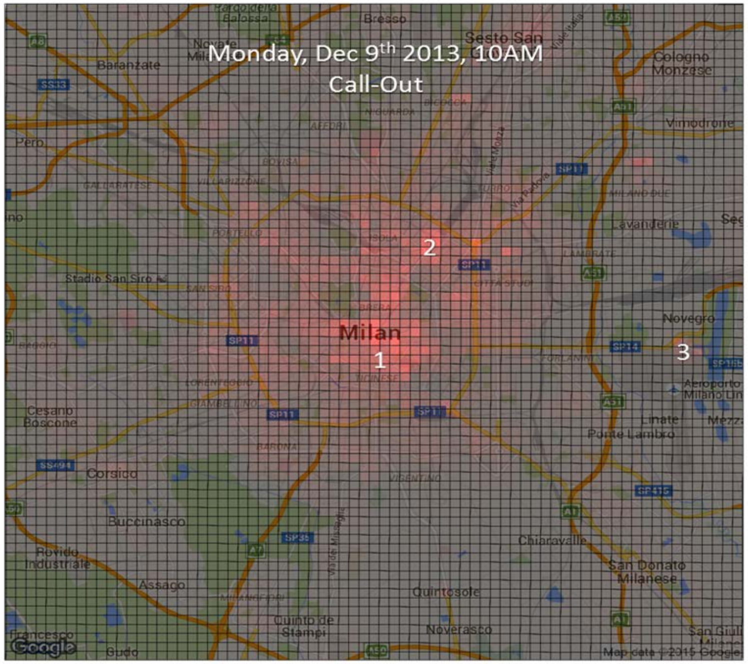
Automatically generated for billing purposes

CALLER ID	CALLER CELL TOWER LOCATION	RECIPIENT PHONE NUMBER	RECIPIENT CELL TOWER LOCATION	CALL TIME	CALL DURATION
X76VG588RLPQ	2°24' 22.14", 35°49' 56.54"	A81UTC93KK52	3°26' 30.47", 31°12' 18.01"	2013-11-07T15:15:00	01:12:02

Example: Milan Italy

Brighter areas = more issued calls:

1) Downtown
2) Train Station
3) Airport



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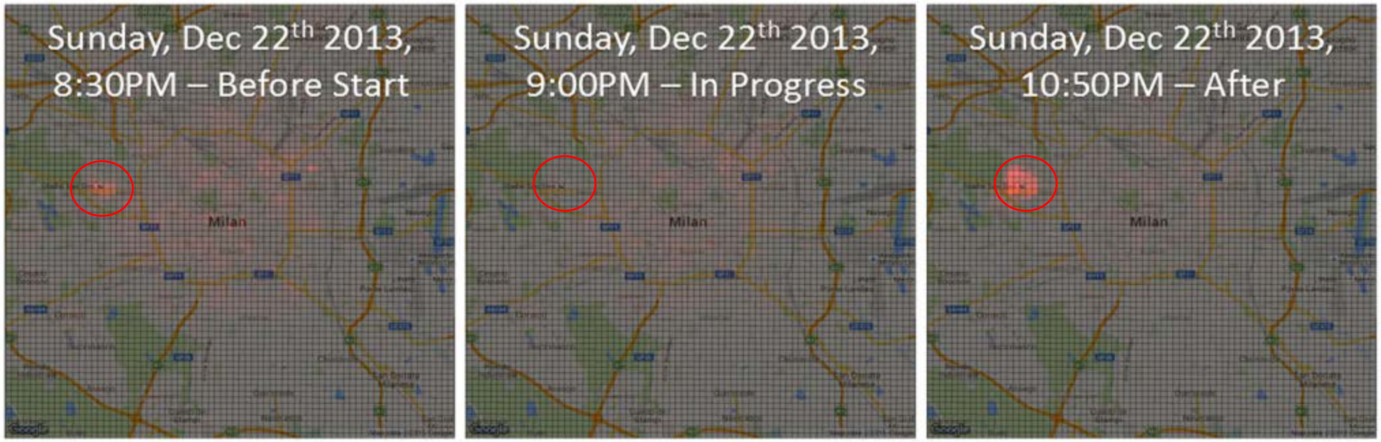
Mobile-Phone Activity to Estimate Occupancy

Reaction to high occupancy events:

Soccer game Sunday Dec 22, 2013: Red circle around San Siro Stadium



Proposed Application:

- <u>Onboard databases</u> can map areas that historically have high/low occupancy.
- <u>Cloud</u> can provide real-time occupancy information.

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Conclusions & Discussion

- New data sources can revolutionize sUAS autonomy and safety
  - Examples discussed here:
    - “Trusted, certified geofencing”
    - “Emergency flight management”

- Remaining Challenges:
  - Open-access data: reliability/trust, update process
  - sUAS “rules” for BVLOS flight: Airspace access v. property rights
  - Autonomy: V&V, trust: Data/learning can help!!!!

- Transition to V2C2V architecture: Manned and Unmanned Aviation

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